ELEMENTS IN THE PROCESS OF RECOVERY BY *CROCODYLUS POROSUS* (REPTILIA : CROCODILIDAE) IN THE EAST ALLIGATOR RIVER AND ASSOCIATED WETLANDS

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This paper reports the results of spotlight surveys from 1977 to 1987 of *Crocodylus porosus* populations in the tidal East Alligator River and its associated freshwater wetlands. Comparative data on the size and structure of the tidal and freshwater 'subpopulations' are analysed and recovery assessed since protection of the species in 1971.

The population in the tidal river has increased significantly at an annual rate of 0.06. Hatchling production in the tidal river has increased significantly at an annual rate of 0.14. In contrast to the absence of any significant long term increase in the numbers of non-hatchling crocodiles in the mid and downstream sections of the tidal river, non-hatchling crocodiles in the upstream section (>55km) have increased significantly at an annual rate of 0.14. This increase in the number of crocodiles in the upstream section is largely accounted for by animals >1.2m in length which have increased significantly at an annual rate of 0.11.

The data reveal major differences in the population structure between the tidal river and freshwater wetlands. Recruitment into the population is essentially confined to the tidal subpopulation, and is concentrated in the midsection of the river. The absence of suitable nesting habitat severely limits successful nesting in freshwater.

The tidal and freshwater subpopulations do not appear to be mutually exclusive. Increases observed in the freshwater subpopulation although not statistically significant, are surmised to have been derived from the tidal subpopulation. Regular seasonal movement of non-breeding crocodiles >1.2m in length between the tidal and freshwater habitat occurs during the wet season and following dry season. This movement is localised in the upstream section of the river and is thought to be the principal mechanism by which animals enter freshwater habitat.

Crocodylus porosus populations in the East Alligator River System have responded positively to protection and the amelioration of habitat degradation that has resulted from the active control of feral Asiatic water buffalo *Bubalus bubalis* in Kakadu National Park by the Australian National Parks and Wildlife Service. ☐ *Crocodiles, Crocodylus porosus, East Alligator River, survey.*

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Crocodylus porosus populations inhabiting the tidal rivers of northern Australia have been described by Messel et al (1979, 1981) as a result of comprehensive spotlight surveys. In that work the authors indicated that saltwater crocodile populations, despite a number of years of protection, were still in a depleted state. They suggested, however, that the extensive freshwater swamps associated with the tidal rivers that comprise the Alligator Rivers Region may act as important recruitment centres or rearing stockyards for sub-adult crocodiles and hence the rate of recovery in these rivers could be expected to be more rapid relative to most other tidal rivers in northern Australia.

STUDY AREA

The East Alligator River drains the escarpment country of western Arnhem Land and flows in a generally northerly direction through extensive sub-coastal floodplains into Van Diemens Gulf. The river is tidal for a distance of 84.5km upstream from its mouth (Fig. 1). The influence of all tides in the extreme upstream sections of the East Alligator River except those associated with full and new moon phases is largely impeded by the presence of a concrete causeway at Cahills Crossing (84.5km). Fringing vegetation, salinity and temperature profiles for the East Alligator River are described by Messel et al. (1979).

Magela Creek traverses subcoastal floodplains and enters the East Alligator River 49.7km upstream from the mouth. It is characterised as a series of discrete fresh waterbodies (billabongs) of varying size and depth in the late dry season (October - November). During the wet season when rainfall and run-off substantially increase water levels,individual billabongs become connected and inundate adjacent low-lying countryside forming extensive areas of fresh water with emergent vegetation.

Mean annual rainfall in the study area is 1556mm, 82% of which occurs between December and March (Bureau of Meteorology - Jabiru Recording Station). The result of this rainfall pattern is a distinctive wet summer and dry winter.

SURVEYS

Tidal River

Surveys were conducted from 1980-1985 under varying seasonal conditions. However, greatest effort was concentrated in the early (April-May) and late (October-November) dry seasons to coincide with hatchling recruitment and minimum discharge of freshwater from the catchment respectively. No survey was undertaken when the volume of fresh water discharge was sufficient to breach the banks of the river.

Crocodiles inhabiting the tidal section were counted at night from a boat using a 12 volt/100 watt sealed beam spotlight. The survey area extended from the confluence with Cooper Creek (13km from the mouth) to Cahills Crossing (84.5km from the mouth). Cooper Creek was not surveyed, however, two tidal creeks intersecting the west bank of the river (Creek A at 32.9km and Magela Creek at 49.7km) were included in the surveys (see Fig. 1). Survey procedure described by Messel et al. (1981) was adopted with the following modification. The east and west banks of the East Alligator River between Cooper Creek and the 50km mark were surveyed on consecutive nights. Because of the extreme width of the river below 50km and limitations in personnel and equipment both banks could not be surveyed simultaneously. Most *C. porosus* are sighted at the water's edge; we assumed that movement between banks was minimal and, if it does occur, movement east would be the same as movement west.

Surveys were carried out in the East Alligator River from Cooper Creek in an upstream direction on a half rising tide during periods coinciding with high tides in excess of 6 metres (i.e. full or new moon phases). The extreme upstream section (74km–84.5km) of the river is not navigable on tides <5.5 metres because of sand and rock bars.

Each crocodile located in the spotlight beam was approached and its total length estimated in one foot categories. Animals greater than 10ft in length were assigned to the one category (>10ft). For analyses, size class data were grouped into the following categories; hatchling, 2-3 ft (0.6-0.9m), 3-4 ft (0.9-1.2m), 4-6 ft (1.2-1.8m) and >6 ft (>1.8m). Animals that could not be approached were scored as 'eyes only'. Animals in the 'eyes only' category were allocated to the >1.8m size class if they were sighted in midstream, or if the spacing between the eyes indicated a large animal. This category represented on average approximately 23 per cent of observations. The 'eyes only' component of the population that could not be ascribed with certainty to the >1.8 m category was treated in the following manner. The size frequency composition of crocodiles for each 5 km length of the river was determined and the remaining 'eyes only' component for each section was allocated proportionately among size classes >0.9m. Experience has shown that crocodiles <0.9m are easily approached and sized. If these crocodiles submerge on being approached, they surface nearby almost immediately and their size can be estimated. The location of each animal sighted was plotted onto a calibrated river map compiled by Messel et al.(1982).

Freshwater Wetlands

On the basis of broad vegetation type the area was stratified into the following three zones: (a) floodplain; (b) woodland; and (c) *Melaleuca* corridor separating the first two zones. Sample billabongs (see Fig. 1) were selected randomly from a pool of accessible billabongs in each stratum. This paper deals only with those situated in strata (a) and (c). Each billabong was surveyed during October or November prior to the onset of the monsoonal wet season when the area of surface water was at its minimum.

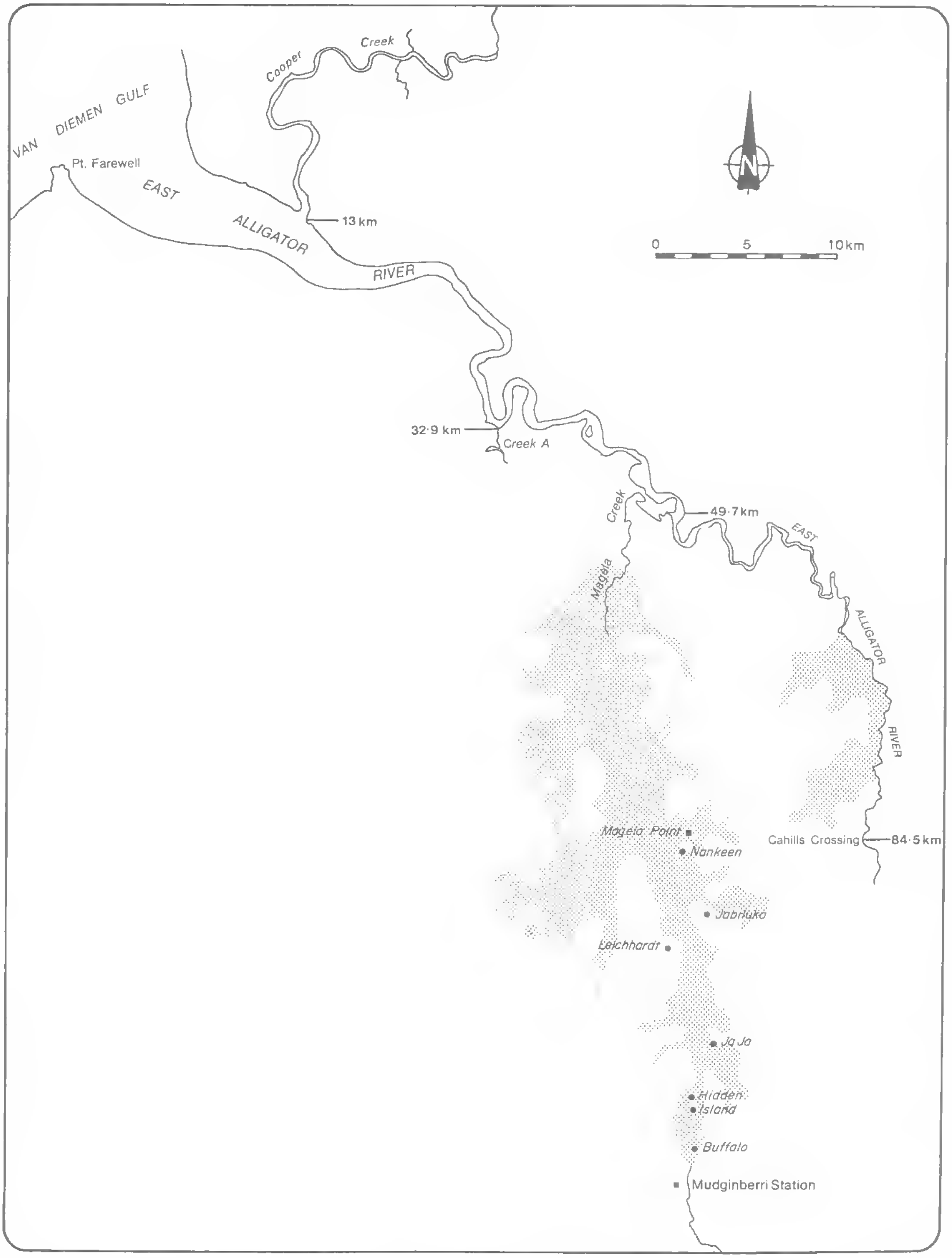

FIG. 1. The study area within Kakadu National Park showing the location of survey billabongs on Magela Creek in relation to the East Alligator River.

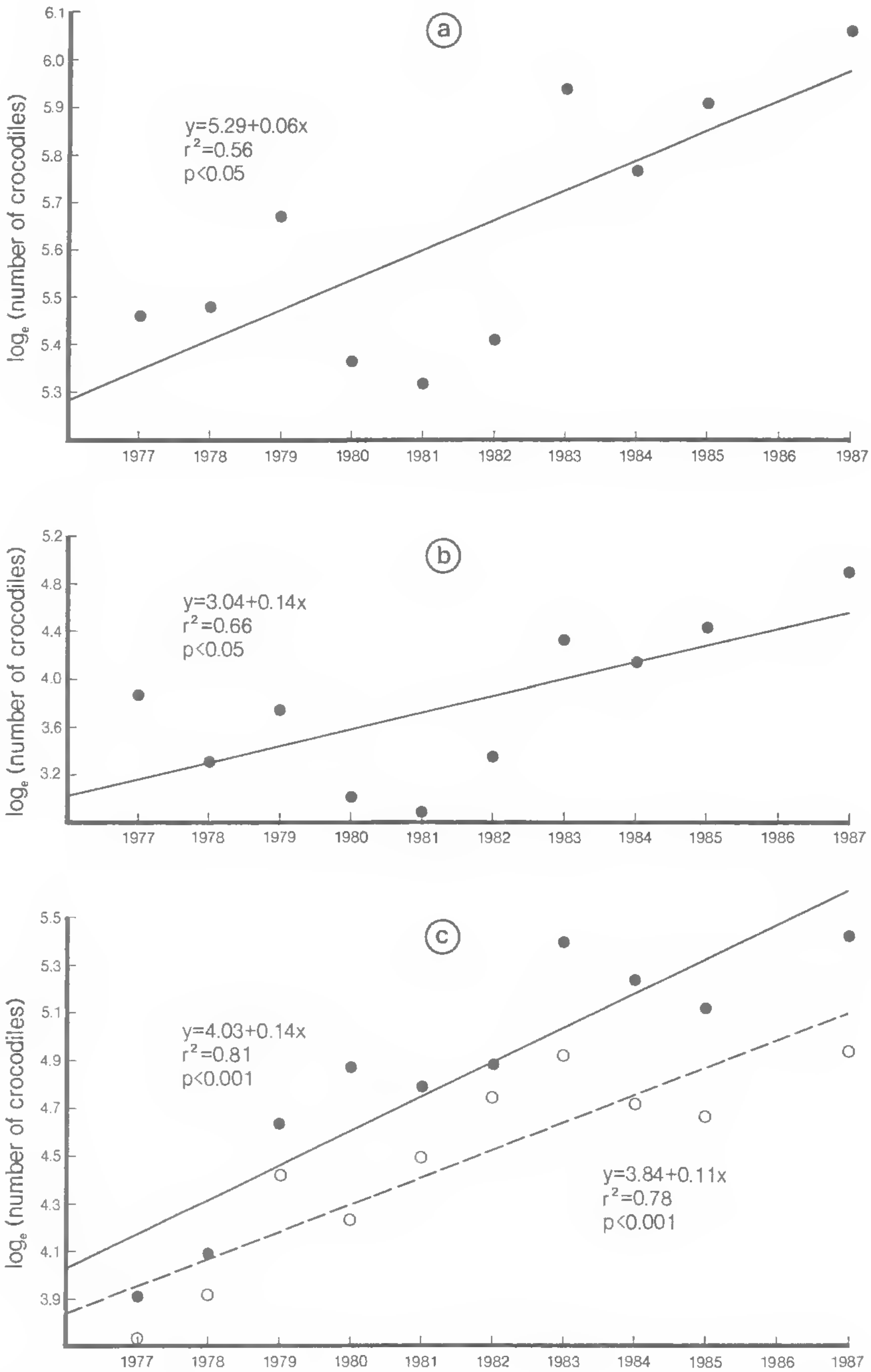

FIG. 2. Regression line relationships between late dry season numbers of crocodiles (natural logarithms) sighted in the tidal East Alligator River and year. (a) Total number of crocodiles in the river. (b) Total number of hatchling crocodiles in the river. (c) Total number of crocodiles in the river (solid datum points and line) and number of animals > 1.2m in length (hollow datum points and dashed line) upstream of 55km. Regression formulae apply x=1,2,3 etc. where 1=1977,2=1978 etc.

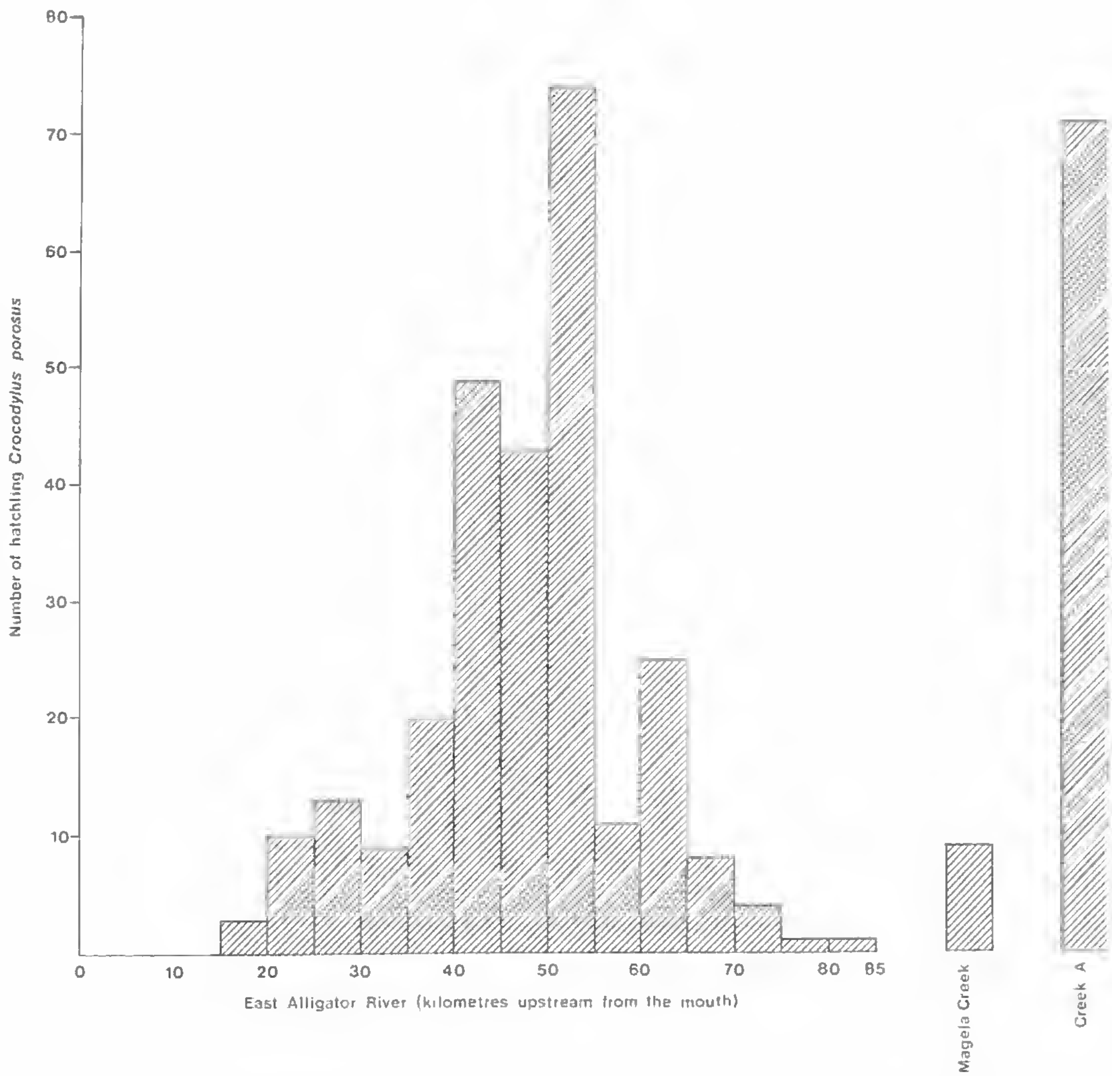

FIG. 3. Distribution of hatchling *C. porosus* in the East Alligator River, 1977–83. (N=351 where N represents the sum of maximum number recorded annually).

Crocodiles were counted with a spotlight from a boat or from the edge of the billabong on foot. Species identification and size, where possible, were recorded for each crocodile observed. In the billabongs sampled *C. porosus* was invariably the only species of crocodile sighted.

RESULTS

Tidal River

The numbers of *C. porosus* sighted during spotlight surveys in the tidal East Alligator River are presented in Table 1. A linear regression analysis of the transformed late dry season data (ln of the total number of crocodiles sighted in the river) against year for the period 1977-1987 (Fig. 2a) indicates a significant relationship (r^2= 0.56, $p < 0.05$). The slope of this relationship is 0.06.

A significant relationship was found to exist when a similar analysis was performed (Fig. 2b) on the late dry season data on the total number of hatchling crocodiles sighted in the river against year (r^2= 0.66, $p<0.05$, slope = 0.14)

The rate of increase in the number of hatchling crocodiles in the river does not reflect a uniform distribution of this age class in the river. Maximum numbers of hatchling *C. porosus* recorded each year from 1977 to 1979 (Messel et al., 1979, 1980) and 1980 to 1983 have been pooled for 5 km segments and presented in Fig. 3. Survey data for 1985 and 1987 were gathered in a manner that did not facilitate this form of analysis. Regular annual recruitment during this period has been generally restricted to the mid-section of the river (30km-55km) and Creek A.

In comparing the 1977 late dry season data (Messel et al., 1979) with those for November 1983 (Fig. 4), the distribution of crocodiles in the river has changed significantly (X^2=58.423, p<0.001). This difference has resulted from a highly significant increase in the abundance of >1.2m long crocodiles in the upstream section of the river above 55km(t=9.771, p<0.001). Linear regression analyses performed on the transformed late dry season data (ln of the total number of crocodiles sighted) for this section of the river against year for the period 1977-1987 (Fig. 2c) show the annual rate of increase (slope = 0.14) to be highly significant (r^2=0.81, p<0.001) and that it largely comprises crocodiles >1.2m long (Fig. 2c) which have been increasing annually in this section of the river at 11 percent (r^2=0.78,p<0.001).

Although the slopes of regression lines for crocodiles >1.2m in length elsewhere in the river for the period 1977-1987 are positive, the relationships are not significant.

FRESHWATER WETLANDS

The number and sizes of *C. porosus* recorded in freshwater billabongs which characterise Magela Creek in the late dry season are summarised in Table 2. There is some difficulty in interpreting crocodiles recorded as 'eyes only' in freshwater habitat. The 'eyes only' category in freshwater habitats constitutes a greater component of the sightable population than in tidal rivers. It is not possible to approach animals in shallow water, very often located amongst fallen timber and/or grasses, to determine a size. We assumed that the frequency distribution of animals able to be sized is a reflection of the entire population and apportioned the 'eyes only' component among the size classes recorded.

The size structure of the freshwater population differs from that inhabiting the tidal East Alligator River in that there is an almost total absence of hatchling and yearling (0.6–0.9m) crocodiles (Table 2). These data suggest that recruitment within the freshwater populations of *C. porosus* is absent or at best minimal.

No statistically significant increase in numbers of crocodiles in comparable billabongs was detected for the period 1980 to 1985 (Table 3). Whilst there has been an increase in the number of *C. porosus* in some of the sampled billabongs, there has been little change in others. Comparisons with surveys of a small series of Magela Creek billabongs undertaken in 1977 (Messel, pers. comm.) indicate an obvious increase in abundance of crocodiles between 1977 and 1980. However, the increase is not statistically significant. This may in part be explained by the inability to sight crocodiles in some billabongs in the latter stages of the study and the small sample size. Surveys of Leichhardt Billabong could not be conducted in 1984 and 1985 because the entire surface of this waterbody was covered with the introduced aquatic plant *Salvinia molesta*. This plant was also present on Jabiluka and Nankeen Billabongs during the 1985 surveys and severely hindered progress on the water and the ability to locate crocodiles in previously accessible areas.

DISCUSSION

Messel et al. (1981) modelled the dynamics of *C. porosus* in tidal rivers of northern Australia based on (a) the suitability of a river for crocodile breeding being determined by its salinity characteristics and (b) movement of non-reproductive animals from breeding rivers into non-breeding areas. In considering the East Alligator River system, Messel et al. (1981) recognised the potential importance of the freshwater swamps but were unable to quantify it.

Jenkins and Forbes (1985) found that for the East Alligator River the distribution as well as the size class structure of *C. porosus* inhabiting the tidal river in the late dry season (October - November) differed significantly from that during the early dry season (April - May). They also found that generally *C. porosus* abundance in the river was greatest at the end of the dry season.

Analysis of the total numbers of crocodiles sighted in the river during the late dry season for the period 1977-1987 indicates an annual rate of increase of 0.06 (Fig. 2a). This rate is marginally lower than the annual rate of increase of 0.07 derived by Bayliss (1987) and Webb et al. (1989)

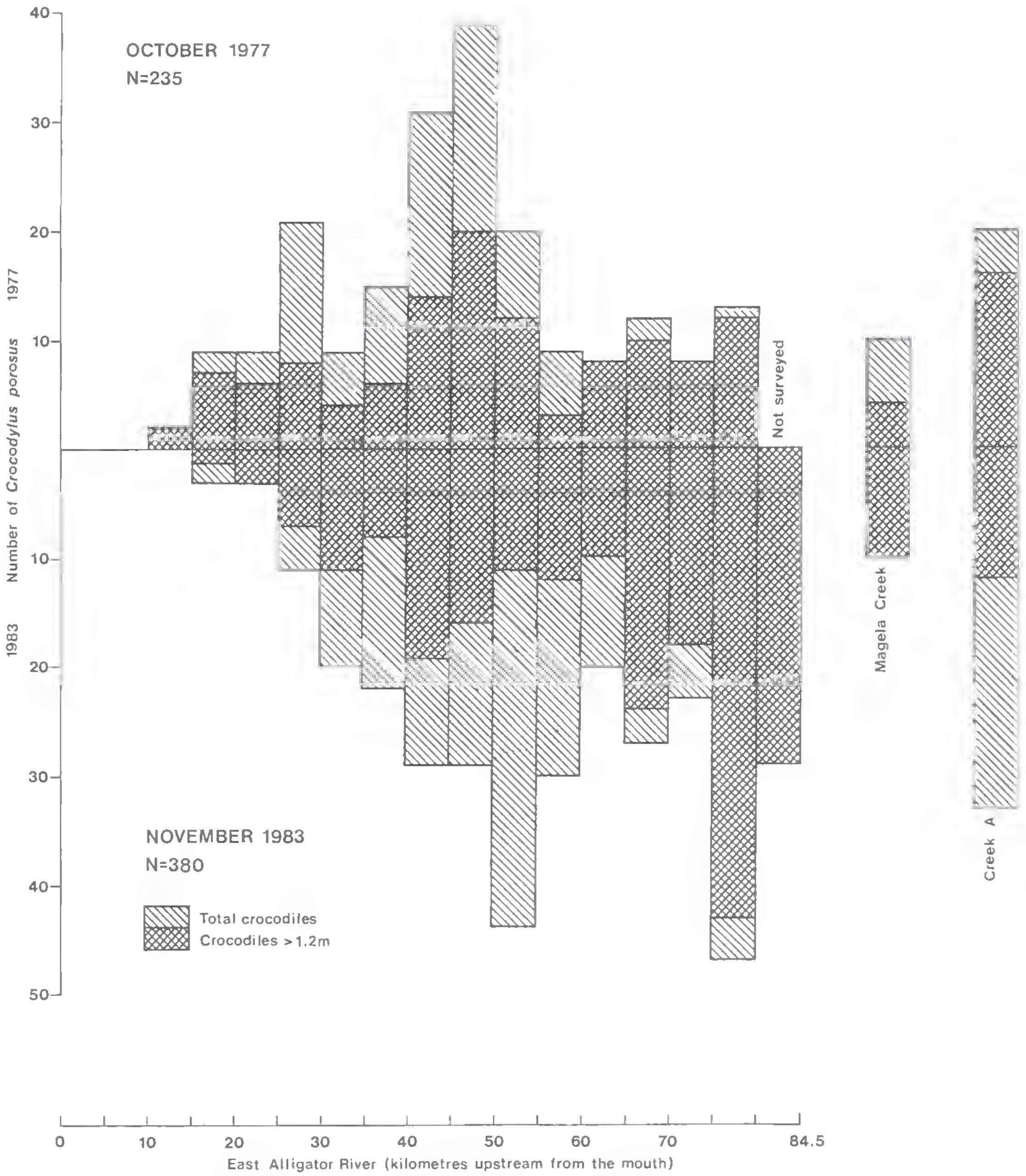

FIG. 4. Distribution of *C. porosus* sighted during late dry season spotlight surveys in the East Alligator River system in 1977 (above line) and 1983 (below line). 1977 data from Messel et al. (1979).

for the period 1977- 1985. This difference in the rates of increase may be due to the two additional years recovery and the omission from this study of (a) Cooper Creek - a major tributary of the East Alligator River, and (b) results of surveys undertaken during the early dry season to avoid incorporating in the regression analysis large numbers of hatchling crocodiles that enter the population during the period but are subject to high mortalities between the early and late dry season (Jenkins and Forbes, 1985). Notwithstanding, it is to be expected that the rate of

TABLE 1. Numbers of *C. porosus* in various size classes sighted in the tidal East Alligator River system during spotlight surveys

	Hatchlings	2-3ft (0.6-0.9m)	3-4ft (0.9-1.2m)	4-6ft (1.2-1.8m)	>6ft (>1.8m)	Eyes only	N
June 1980	26	29	29	39	30	45	198
October 1980	21	16	41	51	41	43	213
July 1981	23	18	24	56	46	34	201
November 1981	17	20	19	58	54	36	204
April 1982	89	26	12	20	28	32	207
November 1982*	29	11	11	49	79	44	223
June 1983	52	47	22	19	81	39	260
November 1983	78	50	20	60	142	30	380
May 1984	34	34	7	19	45	21	160
November 1984	65	34	22	57	74	68	320
November 1985	83	34	28	64	110	48	367
October 1987**	134	20	13	28	159	74	428

*partial survey (13-30km not surveyed). ** ex–Conservation Commission of the Northern Territory

increase in a recovering population will tend towards zero in the long term. It is therefore of interest that the rate of increase in the East Alligator River is lower than the mean annual rate of increase of 0.08 for all crocodiles calculated by Webb et al. (1989) for 26 tidal rivers in the Northern Territory.

Hatchling production has been variable in the East Alligator River. When initial mortalities have been discounted through regression analysis of late dry season sightings, the annual rate of increase for the period 1977-1987 has been significant at a rate of 0.14 (Fig. 2b). Nesting activity has generally been restricted to the mid section of the East Alligator River (30km-55km) including Creek A and Magela Creek although in later years there has been increased nesting activity in the upstream sections above 55km.

Recruitment to the population is essentially confined to the tidal East Alligator River. Hatchling production in freshwater is minimal or absent because of the limited availability of suitable nesting habitat (Wells, 1980). In the absence of such habitat nesting effort in freshwater is generally unsuccessful as nests are subject to inundation with concomitant high egg mortality.

The size structure and distribution of the population inhabiting the river have changed significantly since 1977. This study demonstrates a highly significant increase in upstream numbers of crocodiles at an annual rate of 0.14 (Fig. 2c) has occurred in the period 1977-1987. When the size structure of this segment of the population is examined, animals >1.2m in length largely account for the overall increase in the upstream section increasing at an annual rate of 0.11 (Fig. 2c).

The marked seasonal difference in the numbers of crocodiles inhabiting the upstream section of the river results from a significant reduction in the abundance of >1.2m long crocodiles in the early dry season. Jenkins and Forbes (1985) attributed this difference to wet season movement of animals out of the river into adjacent freshwater habitat being facilitated by the flooding characteristics of the East Alligator River. These animals can be considered to be non-breeding as limited nesting activity occurs in this section of the tidal river. The observed increase in the freshwater population can thus be explained as having been derived from wet season movement from the breached upstream sections of the river. In the absence of any significant long-term increase in abundance of non-hatchling crocodiles elsewhere in the river and the virtual absence of hatchling crocodiles in freshwater habitat, the upstream section of the river may be considered the major dispersal corridor to freshwater habitat for animals derived from downstream breeding and nursery areas. The annual concentration and movement of crocodiles >1.2m in length from the upstream section of the tidal river into adjacent freshwater wetlands may also explain the lower annual rate of increase in overall numbers of crocodiles in the East Alligator River relative to the mean rate

	No. of billabongs	Hatchlings	2-3ft (0.6-0.9m)	3-4ft (0.9-1.2m)	4-6ft (1.2-1.8m)	>6ft >1.8m	Eyes only	N
October 1980	4	—	—	3	22	10	22	57
November 1981	6	—	—	4	19	19	26	68
November 1982	6	2	—	2	17	25	31	77
November 1983	8	—	—	1	26	64	22	113
November 1984	7	6	2	10	31	63	35	147

TABLE 2. Numbers of *C. porosus* in various size classes sighted in freshwater billabongs of Magela Creek during spotlight surveys

calculated by Webb et al. (1989) for 26 tidal rivers in the Northern Territory. Movement of *C. porosus* from the East Alligator River to adjacent freshwater swamps was also suggested by Messel et al. (1980) to explain differences observed in the population in 1977 to 1979. Webb et al. (1983) also recorded marked differences in the number of *C. porosus* sighted during wet season surveys in the Adelaide River compared with surveys undertaken in the dry season. This behaviour is consistent with movement documented for other crocodilians in response to rainfall and flooding in Uganda and Northern Rhodesia (Cott, 1961), Louisiana (Chabreck, 1965) and Venezuela (Gorzula, 1978).

The restriction of regular recruitment to the mid-section of the East Alligator River suggests that recovery by the population in the tidal system and associated freshwater wetlands since protection has been derived principally from this area. The most important agent responsible for the destruction of *C. porosus* nesting habitat is the Asian water buffalo *Bubalus bubalis* (Letts et al., 1979, Fogarty, 1982). Excessive numbers of this large feral herbivore have been a major constraint to the rate of recovery of *C. porosus* by limiting available nesting habitat. The appearance of creches of hatchlings in the upstream section of the tidal East Alligator River in later years has accompanied the re-establishment of suitable riverside nesting vegetation following the removal of large numbers of water buffalo by the Australian National Parks and Wildlife Service under the Plan of Management for Kakadu National Park. Similarly, it has been demonstrated elsewhere in Kakadu National Park that floating grass mats become re- established in the freshwater wetlands following the removal of significant numbers of water buffalo (Jenkins, unpubl. data). The increasing stability of these vegetation platforms with time may result in successful breeding by saltwater crocodiles in freshwater habitat.

The results of this study confirm the ability of *C. porosus* to exhibit a rapid response to habitat and harvest protection similar to that reported for other crocodilians, viz. *Crocodylus niloticus* (Blomberg, 1976, Graham, 1976) and *Alligator mississippiensis* (Campbell, 1978). The continuing recovery of the East Alligator River population of *C. porosus* together with those inhabiting the other rivers and associated wetlands of Kakadu National Park that are managed under a regime of national park legislative protection

TABLE 3. Numbers of *C. porosus* recorded in freshwater billabongs of Magela Creekin 1977 (Messel pers. comm.) and 1980-1983 n.s.= not surveyed

	1977	1980	1981	1982	1983	1984	1985
Buffalo	ns	2	1	1	1	4	2
Island	8	11	14	14	11	18	11
Hidden	ns	ns	4	4	1	7	7
JaJa	ns	15	10	14	18	23	18
Jabiluka	1	ns	9	11	9	17	9**
Nankeen	8	28	30	23	20	18	14**
Magela Point	ns	ns	ns	ns	43	56	30
Leichhardt	5	ns	ns	ns	10	ns*	ns*

*100% surface coverage of *Salvinia* sp. **Substantial coverage (>30%) of surface with *Salvinia* sp.

provide a sound basis for continued commercial ranching outside of the conservation reserve network. It also demonstrates the need for management policies for the *C. porosus* resource to be cognizant of and responsive to the increasing potential for interaction between visitors to Kakadu National Park and *C. porosus*.

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